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Propagation or failure of detonation across an air gap in an LX-17 column: continuous time-dependent detonation or shock speed using the Embedded Fiber Optic (EFO) technique

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Abstract

The detailed history of the shock / detonation wave propagation after crossing a room-temperature-room-pressure (RTP) air gap between a 25.4 mm diameter LX-17 donor column and a 25.4 mm diameter by 25.4 mm long LX-17 acceptor pellet is investigated for three different gap widths (3.07, 2.08, and 0.00 mm) using the Embedded Fiber Optic (EFO) technique. The 2.08 mm gap propagated and the 3.07 mm gap failed and this can be seen clearly and unambiguously in the EFO data even though the 25.4 mm-long acceptor pellet would be considered quite short for a determination by more traditional means such as pins.

Introduction

The EFO technique is a relatively new technique that was developed by D.R. Goosman, G.R. Avara, and their collaborators at LLNL for measuring _wave_ speeds (shock and detonation speeds) continuously in time using laser Doppler velocimetry techniques [1]. The velocimetry system used in these experiments is a custom dual-cavity Fabry-Perot velocimeter equipped with a special Fabry-Perot filter to preferentially reduce the non-Doppler shifted component relative to the Doppler-shifted signal. This system has been previously described in some detail [2-4].

This report is a report of data-only. It is focused on results obtained using the EFO-Fabry-Perot system, specifically on the ability of a detonation in a 25.4 mm diameter LX-17 column to propagate or fail due to an air gap in the column. These results were obtained in three separate shots fired at the 10 kg spherical tank of the High Explosives Application Facility (HEAF) at Lawrence Livermore National Laboratory (LLNL). The shots were all fired with the HE at the ambient temperature of the facility which is typically about 24 ^{0}C

Experimental preparations

The LX-17 pellets were from two separate pressings but the molding powder for both pressings was LX-17-1 from LLNL sample number C-063. The molding powder was hot ram-pressed to a density ranging from 1.913 to 1.916 g/cc. A special die set with a central pin was used to press the pellets with a hole to accommodate the probe without resorting to an additional drilling operation. The 1.60 mm diameter hole is located on the pellet axis and makes a snug fit with our polytetrafluoroethylene (PTFE) clad / aqueous CsCl solution core probe. A PBX-9501 pellet with hole was used as a booster and an RP-1 detonator [5] was used to initiate the 9501. A diagram representing the configuration of all the shots is shown in Fig. 1.

Average density for each pellet was determined as mass / volume. Volume was computed from the measured height and diameter of each pellet. We believe our accuracy on the mass / volume measurement is about 0.1%.

The shots were all fired horizontally in pine-wood V-blocks. Hence for all intents and purposes the shots are unconfined and can be simulated with an appropriate 2-D hydrocode to test various LX-17 models.

The gaps were set and maintained by small Lucite shims. The shims contacted the HE at two small-area locations near the perimeter of the column (for example, see Figs. 2 and 3) hence the gap material was effectively RTP air and not Lucite. Although we did not do a detailed assessment of gap accuracy we expect the gaps to be accurate to about 2 mils or 50 microns, roughly one to two percent of the gap width.

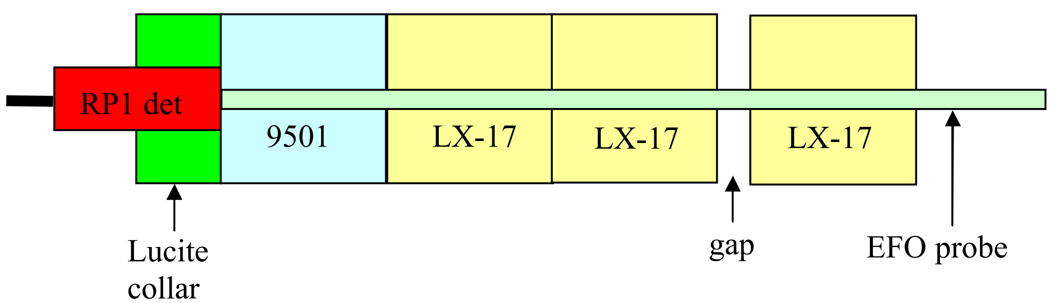

Fig 1. A diagram of the configuration used for the three "gap shots" GGR225 (3.07 mm gap), 226 (2.08 mm gap), and 227 (no gap). The EFO probe can be reasonably modeled as a solid rod of PTFE that is 1.60 mm diameter. The Lucite collar that holds the detonator in place is about 12.7 mm in length and the same diameter as the rest of the column. The gap and confinement are both RTP air.

GGR225, 3.07 mm gap		
Pellet ID	Mass/volume (g/cc)	Length (mm)
9501012507-1	1.828	25.40
LX17052506-6	1.915	25.35
LX17052506-9	1.914	25.37
Gap	RTP air	3.07
LX17052506-10	1.915	25.36
GGR226, 2.08 mm gap		
9501012507-2	1.830	25.37
LX17052506-4	1.913	25.36
LX17052506-5	1.916	25.34
Gap	RTP air	2.08
LX17052506-8	1.914	25.37
GGR227, no gap		
9501012507-3	1.829	25.36
LX17112806-9	1.914	25.37
LX17112806-15	1.913	25.41
No gap	NA	0.00
LX17112806-16	1.914	25.39

Table 1: Initial densities and measured lengths of the pellets of GGR225, 226, and 227. For a given shot the sequence is of increasing distance from the detonator as you go down the table, with the 9501 pellets being next to the detonator, etc. The diameters of all the pellets can be taken to be 25.4 mm.

Experimental results

Figure 2: GGR225 (3.07 mm gap) set-up photo. The gap is just left of the thin strip of black tape and the two Lucite shims to maintain the gap can be seen resting against the surface of the V-shaped channel. "Top" represents the pellet end-face that was against the moving plunger during the pressing operation.

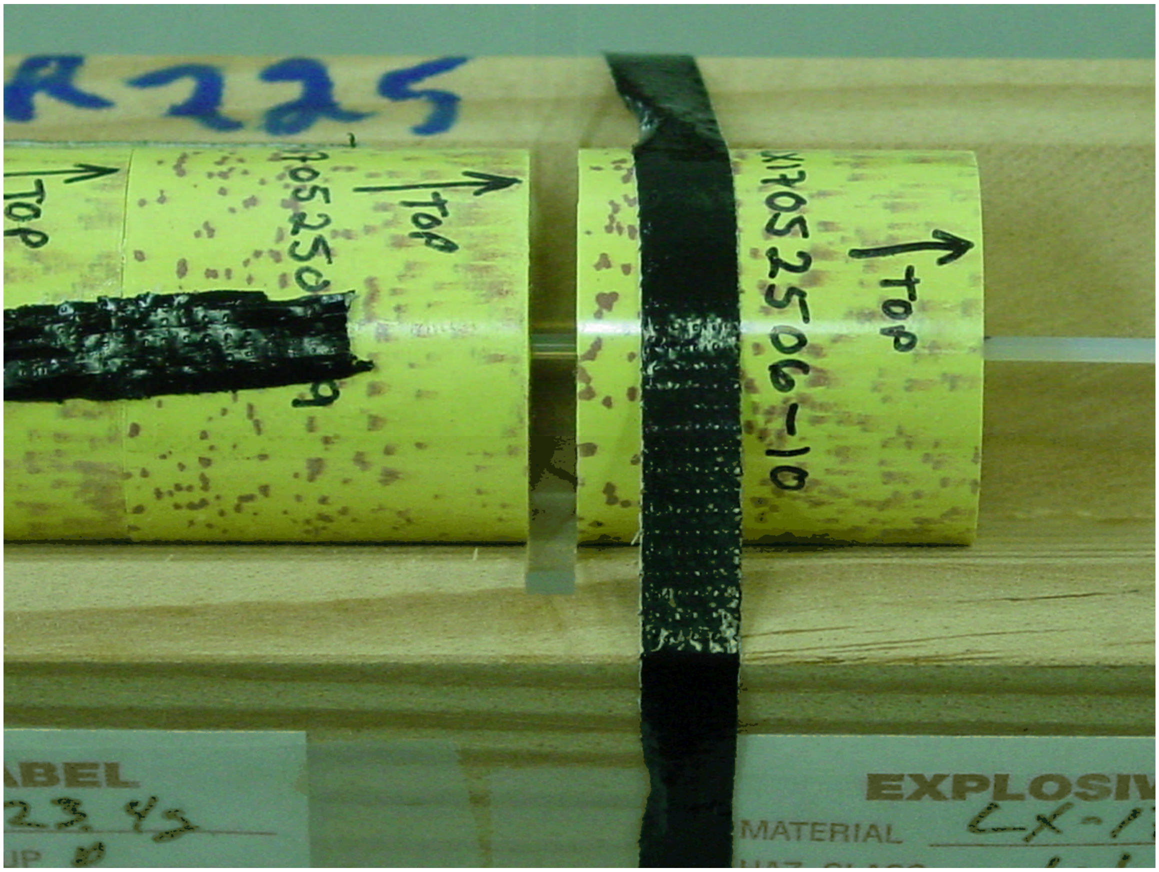

Figure 3: GGR225 close-up of the air gap and shims.

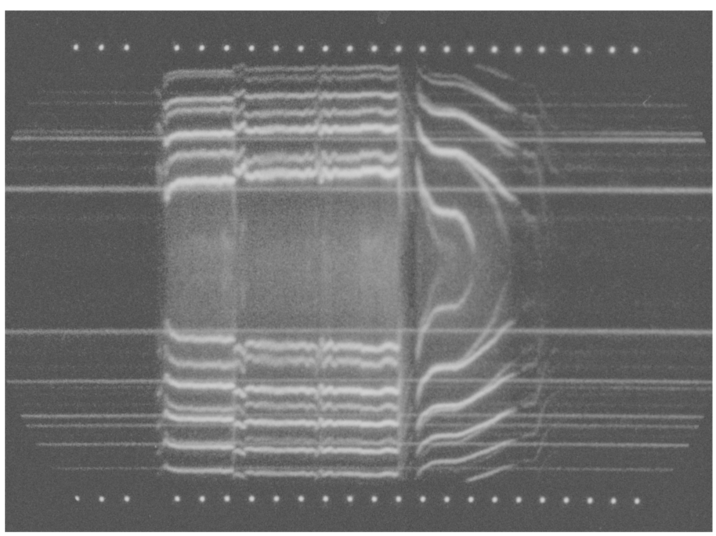

Figure 4: GGR225, 3.07 mm air gap, Fabry-Perot velocimeter fringe history. The time dots on all the fringe histories are spaced 1.00 μs apart

Figure 5: GGR226, 2.08 mm air gap, set-up photo

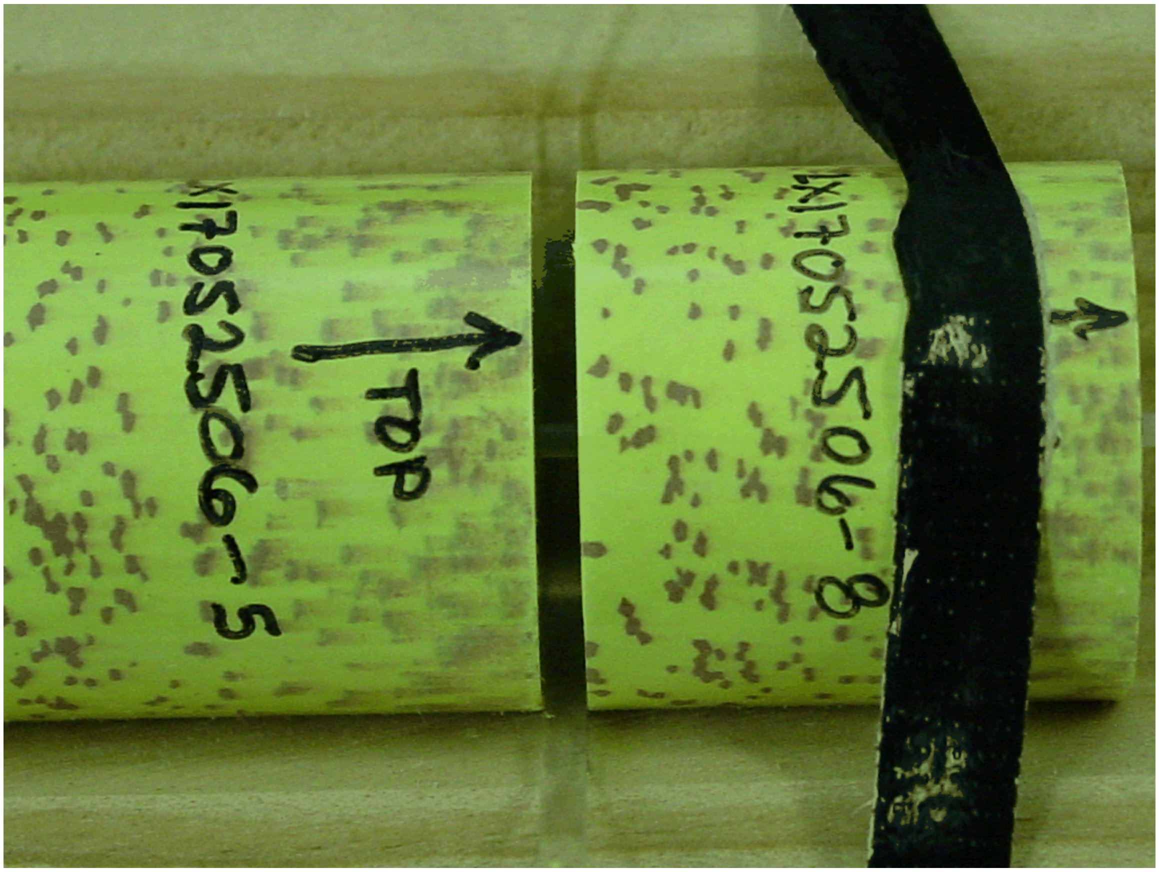

Figure 6: GGR226, close-up of air gap and shims

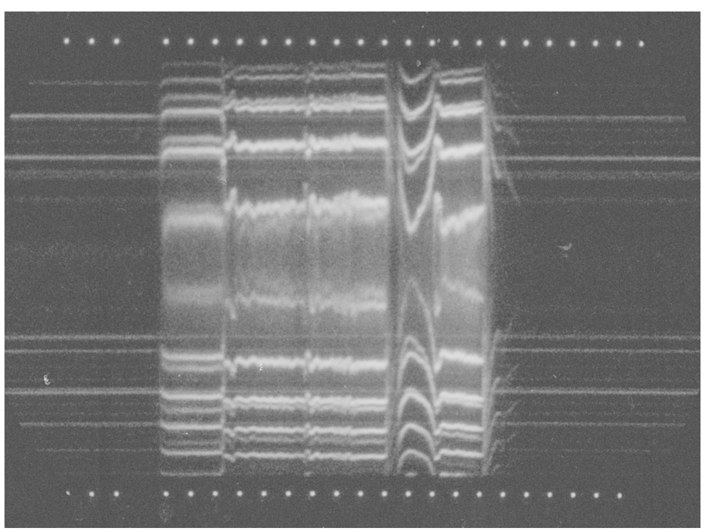

Figure 7: GGR226, 2.08 mm air gap, F-P velocimeter fringe history

Figure 8: GGR227, no gap, set-up photo

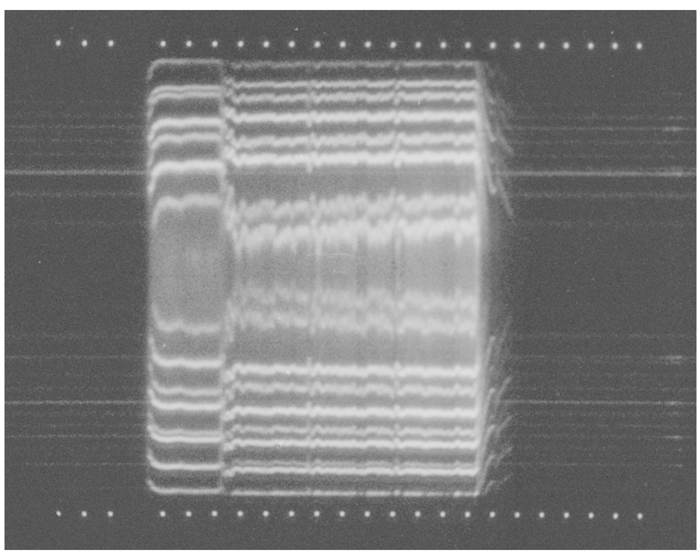

Figure 9: GGR227, 0.00 mm (i.e. no) air gap, F-P velocimeter fringe history

Analysis of fringe histories to obtain shock and detonation speeds

Fringe histories were analyzed in two different ways: by hand by carefully measuring the fringe diameters at a few discrete points and then completing the resultant analysis on a spreadsheet. This we refer to as the “hand” analysis. The second method was by using a computer routine Fabryvb6, developed by G.R. Avara [6] (the “machine analysis”).

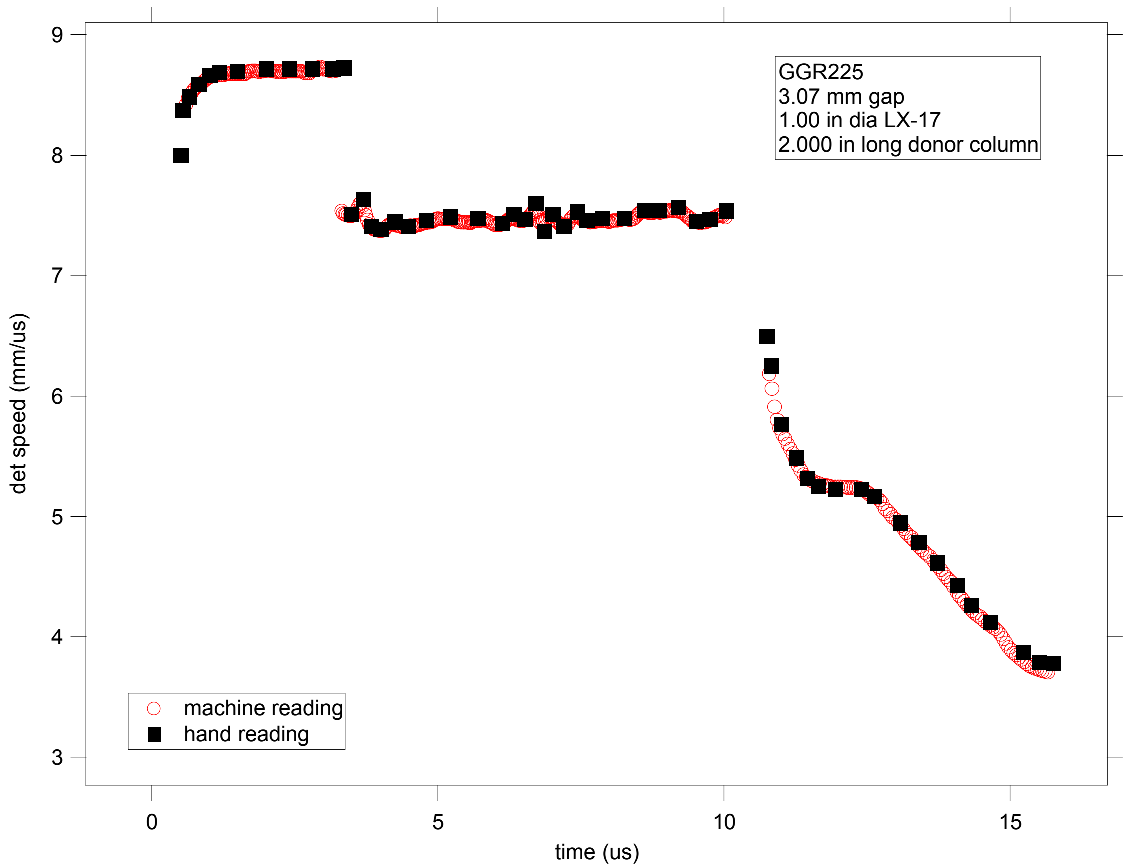

Figure 10: Detonation / shock speed history from GGR225 (3.07 mm gap). It is abundantly clear by the abrupt decrease of shock speed below 7 mm/µs in the acceptor that the detonation failed to propagate in the acceptor pellet. Some unburnt LX-17 powder was found after this shot clearly indicating that the acceptor pellet was not fully consumed.

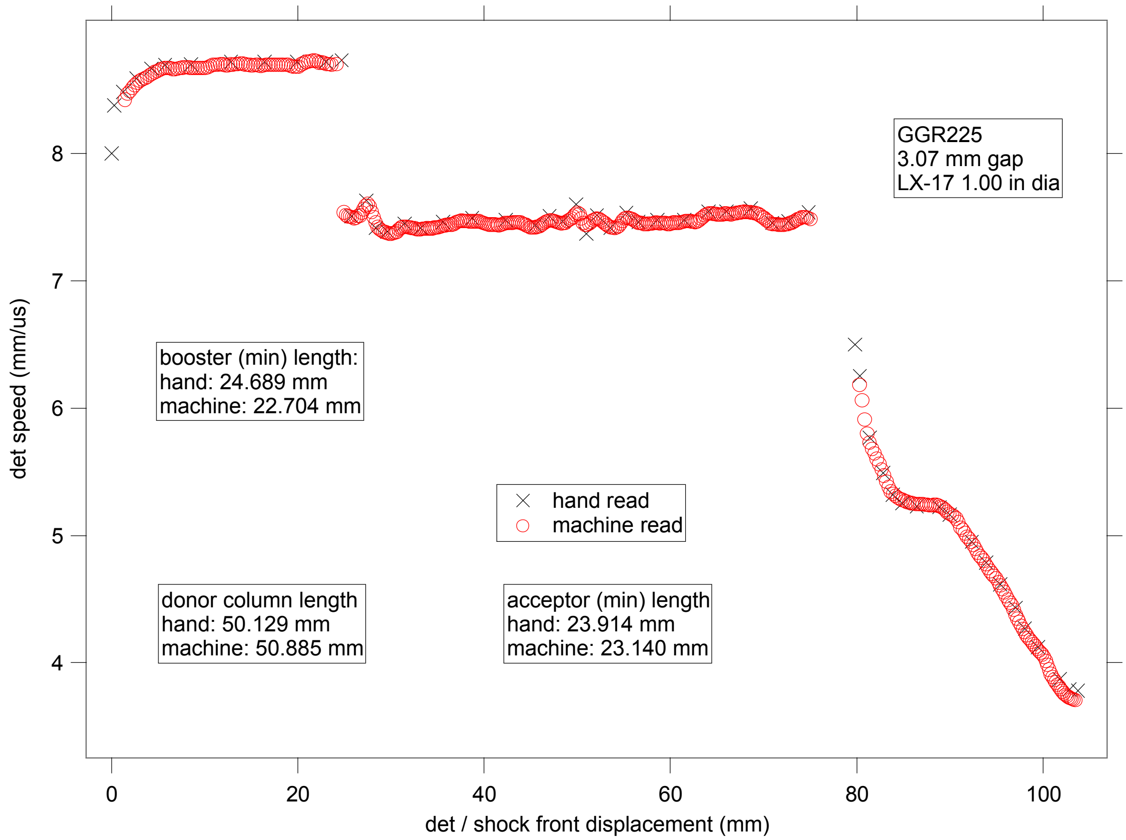

Figure 11: GGR225 (3.07 mm gap) detonation / shock speed vs detonation / shock front displacement.

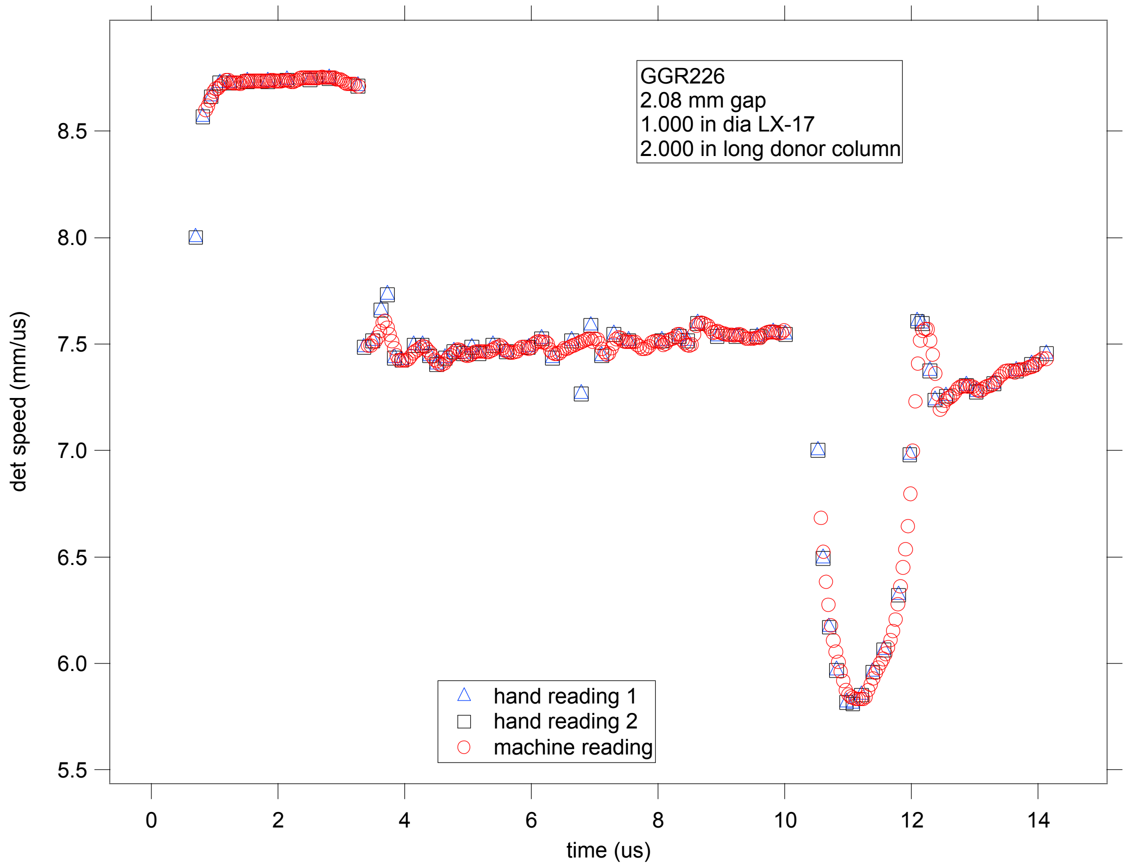

Figure 12: Detonation speed history in GGR226 (2.08 mm gap). Although the detonation hesitated (at about 11 µs), it clearly did eventually propagate and was close to the steady detonation speed by the time the detonation exited the acceptor pellet. There was no LX-17 residue from this shot.

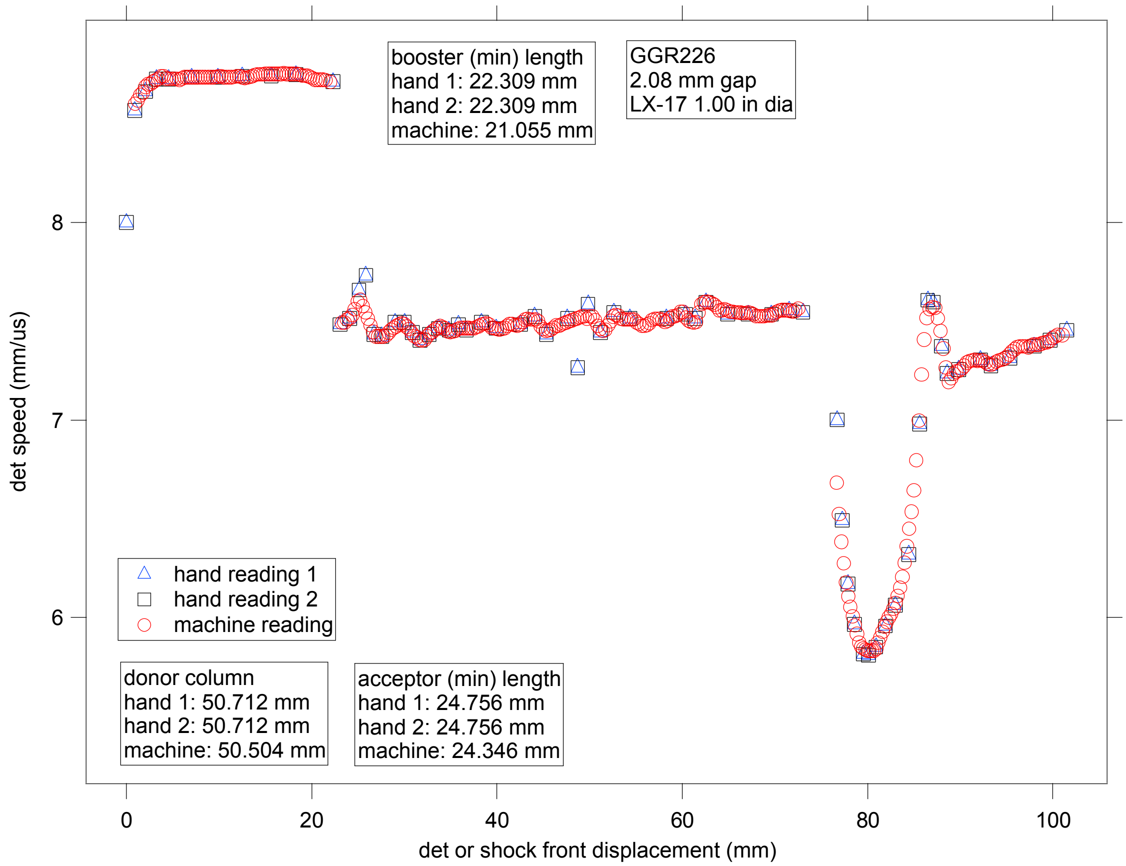

Figure 13: Detonation speed versus detonation front displacement. GGR226 (2.08 mm gap)

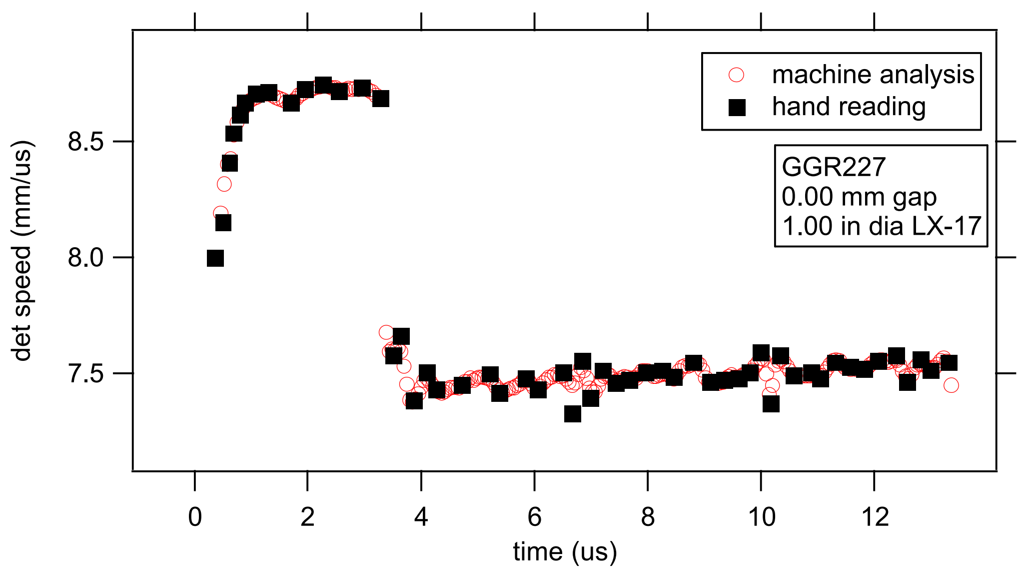

Figure 14: Detonation speed history: GGR 227 (no gap). This shot is for timing purposes.

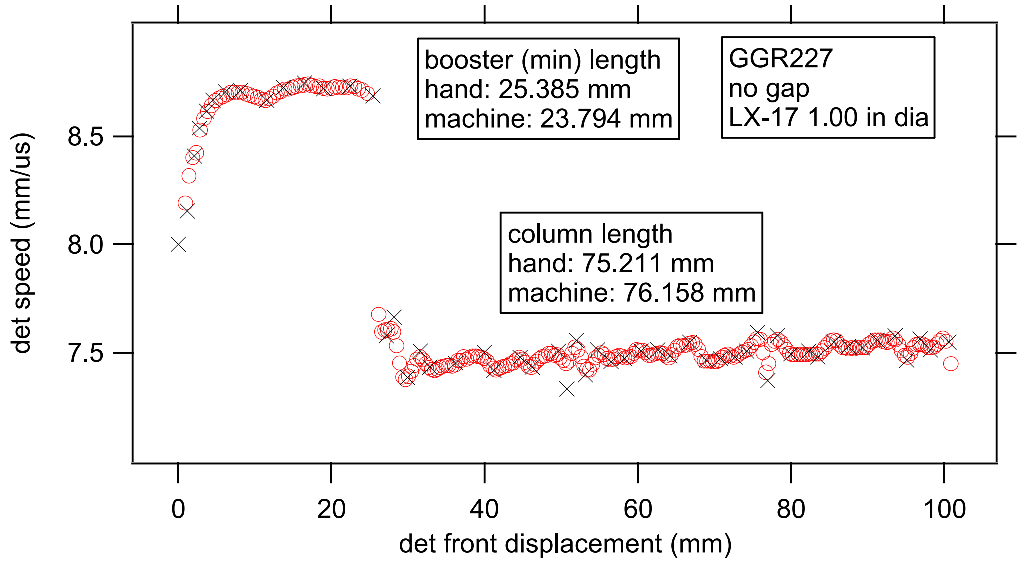

Figure 15: Detonation speed versus detonation front displacement. GGR227 (no gap).

Discussion of the results

There are three natural space-time fiducials that are useful to this series. All three of these occur in GGR225 (3.07 mm) and 226 (2.08 mm), and two of them occur (cleanly) in GGR227 (no gap). They are the exit of the detonation (or shock wave) from the booster, donor, and acceptor. The time of these exits can be read directly from the fringe histories. The reading of the donor-acceptor junction in the no-gap case of GGR227 is subject to more uncertainty than the others, but a reading was performed anyway and reported along with the other fiducials in Table 2.

In the last column we see that there is a 0.8% spread (52 ns) in the values of "transit time thru donor". This spread is rather large and cannot be attributed either to donor column length differences or donor pellet densities differences (Table 1). We attribute this spread to limitations in our ability to accurately read time from the fringe histories for these data.

We have been a little loose in our terminology up to this point, equating the reported velocities to the instantaneous detonation or shock speed in the HE. To be more precise, this is only approximately correct. We should point out to the reader that the EFO probe accurately measures the speed of the shock wave <u>that exists within the EFO probe.</u> This shock wave is formed by and exists because of the detonation in the surrounding HE. It is therefore strongly correlated with, <u>but not always exactly equal to</u>, the speed of the detonation in the surrounding HE. Particularly when there is a strong time-dependence to the flow (i.e. very far away from steady detonation) there can be a substantial difference between what the probe registers and the detonation or shock wave speed in the surrounding media.

Shot #	Detonation reaches:	Time (μs)	Transit time thru donor (μs)
GGR225, 3.07 mm gap	End booster	3.333	6.726
	End donor	10.059	
	End acceptor	15.716	
GGR226, 2.08 mm gap	End booster	3.340	6.778
	End donor	10.118	
	End acceptor	14.210	
GGR227, no gap	End booster	3.377	6.739
	Donor-acceptor boundary	10.117	
	End acceptor	13.441	

Table 2: Timing. The exit of the detonation (or shock wave) from the booster, donor column, and acceptor pellet for shots GGR225 – 227. "Transit time thru donor" is computed as ("end donor" – "end booster").

In the context of the data of this work, within the latter half of the booster or the donor column the EFO-measured velocities should be very close to the detonation speed in the surrounding material. The strongly-time-dependent behavior at the booster / donor boundary, within the gap, or within the acceptor is another matter. The probe-measured velocities within the acceptor pellet correspond to detonation / shock wave behavior there at about the 5-to-10% accuracy level. However, hydrocode modeling (with the probe included) is required to make a truly quantitative comparison within the acceptor.

Acknowledgements

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References

[1] Willard F. Hemsing of Los Alamos National Laboratory performed some unpublished early pioneering work demonstrating the “EFO effect” and shared his results with D.R. (David) Goosman. David subsequently pursued and refined this into what we presently call the EFO technique. (See the introduction of reference 2)

[2] D.R. Goosman, J.T. Wade, R.G. Garza, G.R. Avara, T.R. Crabtree, A.T. Rivera, D.E. Hare, D.R. Tolar Jr., B.A. Bratton, “Optical probes for continuous Fabry-Perot velocimetry inside materials”, 26th International Congress on High-Speed Photography and Photonics. Edited by Paisley, Dennis L.; Kleinfelder, Stuart; Snyder, Donald R.; Thompson, Brian J., Proceedings of the SPIE, Volume 5580, pp. 517-528 (2005).

[3] D. Goosman, G. Avara, L. Steinmetz, C. Lai, S. Perry, “Manybeam Velocimeter for Fast Surfaces”, Lawrence Livermore National Laboratory report: UCRL-JC-123809, 1996.

[4] David Goosman, George Avara, James Wade, and Anthony Rivera, “Optical Filters to Exclude Non-Doppler-Shifted Light in Fast Velocimetry” Lawrence Livermore National Laboratory report: UCRL-JC-145646-REV-1, 2002.

[5] The RP-1 detonator is an EBW (exploding-bridgewire) detonator manufactured by Teledyne RISI Inc. The details of the RP-1 can be found on their website at www.teledynerisi.com

[6] G. Avara, “Analysis of Fabry-Perot Velocimeter Records”, Lawrence Livermore National Laboratory report: UCRL-ID-145355, 2001